

Virtual Test Bed for Evaluating Wave Prediction Technology

Vincent J. Cardone and Andrew T. Cox
Oceanweather Inc.
5 River Road
Cos Cob, CT 06807

Phone: 203-661-3091 fax: 203-661-6809 email: oceanwx@oceanweather.com

Contract Number N00014-98-C-0135

http://www.onr.navy.mil/sci_tech/ocean/onrpgahj.htm

LONG-TERM GOALS

This contract supports a part of a larger program of applied research whose ultimate goal is to significantly improve our ability to predict ocean waves in deep and shallow water environments. That larger program is organized under ONR's Advanced Wave Prediction Program. The specific part of that program of which our effort is a part addresses the development of a "virtual test bed for evaluating wave prediction technology". This "test bed" project responds to the fact that there have been no significant advances in operational wave modeling and prediction since the introduction of the WAM model over a decade ago. The test bed is intended to stimulate scientists to systematically investigate, implement and test more advanced algorithms (source terms) which simulate wave growth, interaction and dissipative processes in deep and shallow water wave prediction models and to provide a rational objective framework to evaluate the efficacy of model enhancements.

This test bed program is a coordinated collaborative effort between scientists at Oceanweather Inc., the U.S. Army Corps of Engineers Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) , and the U.S. Naval Research Laboratory (NRL).

OBJECTIVES

The specific objectives of Oceanweather's component of the test bed program may be succinctly stated as follows: (1) contribute to the identification and selection of the real historical scenarios to be used to populate the virtual test bed, taking into account at least the following: potential accuracy of wind inputs, suitability of bathymetry, availability and accuracy of measured wave data, spatial and temporal scales of the wave field; (2) for each selected case requiring post-analysis wind fields, develop the most accurate wind fields possible, given the available data base, using detailed kinematic reanalysis; (3) contribute to the assembly and processing of the measured wave data to be used to evaluate the wave model simulations; (4) contribute to the design of the statistical package to be developed for the test bed for objective model evaluations ; (4) contribute to the testing, evaluation and documentation of a prototype virtual test facility to be implemented at WES and NRL in anticipation of its transfer to other systems.

WORK COMPLETED

Selection of Real Historical Scenarios.

Extratropical Storms

The test bed requires wind fields of maximum achievable accuracy so that wind field errors do not mask wave model induced errors. That it was possible to develop wind fields of such accuracy in an extratropical storm regime was first demonstrated by Oceanweather in the SWADE IOP-1 hindcast wind field sensitivity study. The high standard of accuracy of the SWADE IOP-1 wind fields was applied in the consideration of additional cases. Therefore, at the present time we consider only the

following extratropical scenarios suitable for the test bed:

SWADE IOP-1 of October 20-31, 1990

Storm ("Halloween") of October 25, 1991-November 1, 1991.

Storm ("of Century") of March 11-17, 1993.

Tropical Storms

Somewhat larger errors may be tolerated in tropical cyclone wind fields than extratropical cyclone wind fields for the purposes of assessment of wave prediction models because of: (1) the wide dynamic range of wind speeds in tropical cyclones; (2) the relatively tight constraints on the vector wind distribution; (3) the known locus of the center of action (eye) for well documented storms; (4) the strong ocean wave response.. A large number of tropical cyclones have been hindcast at Oceanweather, WES and other centers in recent years. Results of studies of earlier storms have been documented in papers in journals, conference proceedings and informal workshops and simulations of storms in the active North Atlantic seasons of 1995, 1996 and 1998 are underway at several centers. Our assessment of the suitability of all of the possible candidate cases of tropical cyclones, at least in the North Atlantic Ocean/Gulf of Mexico basin, has lead us to select the following cases for the test bed:

Hurricane Camille 1969	Gulf of Mexico
Hurricane Frederick 1979	Gulf of Mexico
Hurricane Andrew 1992	
Hurricane Gordon 1994	North Atlantic
Hurricane Felix 1995	North Atlantic
Hurricane Luis 1995	North Atlantic
Hurricane Opal 1995	Gulf of Mexico
Hurricane Fran 1996	North Atlantic
Hurricane Bertha 1996	North Atlantic
Hurricane Danielle 1998	North Atlantic

Long Term Continuous Wave Climate Simulation

A number of long term continuous wind field series have been produced in recent years including a 17-year ECMWF global reanalysis series, the WASA 40-year North Atlantic series (based on U.S. Navy wind fields) and the NCEP/NCAR 40-year global reanalysis series. The ECMWF and WASA wind series have been already used in toto to drive the WAM-4 model at European centers, and parts of the NCEP series have been used at OWI to drive a different 3G wave model (Swail and Cox, 1998). Validation of those hindcasts indicates that the wind errors are intolerably large for the purposes of the test bed. OWI has already reanalyzed the NCEP winds for the period 1958-1995 over the North Atlantic for the Canadian sponsored 40-year North Atlantic wave climate simulation. The reanalysis of the reanalysis provides considerably improved wave hindcasts. However, for the purposes of the test bed, we recommend selection of the period January 1, 1996-December 31, 1996 with a later possible extension to June 30, 1997 for the test bed. During this period winds may be produced with all of the data sources used for the AES40 study plus one important additional source, namely, wide dual swath surface wind at 50 km spacing obtained from the NSCAT scatterometer flown aboard the ADEOS satellite, which became available beginning in September, 1996 and continued to be acquired until the ADEOS satellite failed on June 30, 1997.

Continuous test case: Calendar year 1996 with possible extension to June, 1997 .

Preparation of Wind Field Data Sets

Wind fields for all of the above cases are provided to the test bed by Oceanweather. There are three possible categories of effort to do this:

Category 1. Wind fields have been already been derived in previous OWI case studies with sufficient accuracy domain, and resolution for the test bed. The incremental work involves therefore, search for and restoration of binary files from various project and system back tapes, transformation of the binary files to OWI' standard WindFile ASCII format after interpolation of the wind fields, if necessary, to a standard ¼ degree latitude-longitude grid.

The following cases fall into this category of effort:

SWADE IOP-1
Halloween Storm
Storm of Century
Hurricanes:
Gordon
Felix
Luis
Fran
Bertha

Category 2. Wind fields have already been derived in previous OWI case studies but some degree of enhancement is considered desirable before they are placed in the test bed. Storms in this category consist mainly of tropical cyclones whose core structure has been satisfactorily modeled using OWI dynamical boundary layer model but for which it would be desirable to expand the domain of the wind field by blending the core structure winds into a high-quality background wind field such as the NCEP/NCAR Reanalysis wind.

The following cases fall into this category:

Hurricane Camille (1969)
Hurricane Frederick (1979)
Hurricane Andrew (Gulf of Mexico) (1992)
Hurricane Opal (1995)

Category 3. Wind fields which have not been generated in previous studies.

The following test bed cases fall into this category:

Hurricane Danielle
Continuous period January –December, 1996 (possible extension to June, 1997)

The full support for the first contract period (\$30,000) has provided sufficient support to cover the

conversions of Category 1 cases, the enhancements of Category 2 cases and the new kinematic analysis of Hurricane Danielle. The basic work of kinematic analysis of wind fields for the continuous year 1996 is supported at OWI by the Atmospheric Environment Service (AES) as part of its 40-Year North Atlantic Hindcast Study and is expected to be completed by calendar year end . Conversion of the continuous winds to test bed format and resolution will be carried out during the next contract period early in 1999.

Details on each selected case may be found in the attachment.

Preparation of Wave Data Validation Data Sets

Buoys/CMAN

Previous wave model validation studies carried out for the selected cases have often had to resort to the use of buoy wave data gleaned from GTS transmissions. This is especially true of data from the Canadian buoy array for which a final quality controlled archive of data had yet to be produced. During this contract we obtained definitive archives of US and Canadian buoy data and wrote software to extract quality controlled and averaged wave data for use in the test bed. US buoy data are taken from the NOAA Marine Environmental Buoy Database CD-ROM set. Canadian buoy data are taken from a prototype copy of the Marine Environmental Data Service (MEDS) Meteorological Data CD-ROM. These CD-ROM sets provide quality controlled hourly observations for the majority of in-situ comparisons. Other buoy and platform data (non-US or Canadian) are taken from the COADS database. That data is usually 3 or 6 hourly and suffers from "banding" as many wave observations were recorded only to .5 meter resolution.

Buoy observations consist of both wave parameters (significant wave height, wave period, and wave direction) and measured spectra depending on the type of instrumentation. Wave parameters are typically available hourly for US and Canadian buoys and vary for UK and North Sea Platforms (3 or 6 hourly). All wave parameters are taken from the source files and smoothed using a running 1,1,1 average (+/- 1 hour with equal weighting). An attempt is also made to remove erroneous and unrepresentative observations in the time-series. At the present time we have no plan to further process buoy wave spectra with no attempt to smooth or match particular frequency bands.

Satellite Altimeter Data Sets

Satellite altimeter data are expected to be most useful for the evaluation of the continuous hindcast case because altimeter wave height observations provide an excellent basin-wide coverage for wave model comparison. In the 1996 continuous NA hindcast year, both TOPEX and ERS-2 altimeter measurements are available and these data sets have been obtained by OWI. TOPEX measurements are taken from the Merged Geophysical Data Record from the Topex/Poseidon Mission Generation B CD-ROM set issued by JPL, while ERS-2 measurements are extracted from the Ifremer/Cersat Altimeter Ocean Products CD-ROM set. Oceanweather's copy of the ERS-2 data was provided by AES/Canada, who have presumably executed a license agreement with ESA which governs the use of the ERS-2 data. Before these data are actually inserted into the test bed it may be necessary for ONR to secure similar

license rights.

Software has been developed and tested to process the altimeter data for use in the test bed. Processing of the altimeter data consists of three steps. First, raw wave height observations and quality control flags are read from the CD-ROM. Both JPL and CERSAT provide recommended quality control parameters used to determine good/bad altimeter measurements. Second, a regression scheme is applied to the data as indicated by studies that compared altimeter measurements with buoy wave height observations. The regressions used are:

Cotton and Carter, 1994 $H_s = 1.024 * TOPEX - .032$	Carter, 1996: $H_s = 1.05 * ERS2 + .04$
---	--

The adjusted data are then binned +/-3 hours (on synoptic times) onto the target NA wave model grid (.5 degree). All observations within the time and grid window are averaged and considered one comparison point.

Special Data Sets

Oceanweather has possession and license to utilize several unique data sets obtained by the offshore oil industry in some of the selected cases. These include wave parameter time series measured from offshore platforms in the Gulf of Mexico in hurricanes Camille, Frederick, Andrew and Opal and directional wave measurements from Shell's Cognac platform obtained in hurricanes Frederick and Opal. Except for these data, which have already been processed, OWI have no plans to assemble or otherwise process special third-party wave data sets such as exemplified below.

Other special data sets have been obtained by US and Canadian government agencies, including measurements in Hurricane Andrew in shallow water in the northern Gulf of Mexico and in and offshore its FRF in recent (post 1990) U.S. east coast tropical and extratropical cyclones and by Environment Canada as part of its SWS (Storm Wave Study) which involved the deployment of a high-performance NOMAD buoy during 1997-98 on the Grand Banks near the Hibernia platform.

Directional spectra derived from ERS2 SAR are potentially available from European sources for evaluation of the continuous hindcast test bed case.

PLAN FOR NEXT CONTRACT PERIOD

1. Upon final agreement with the Program Officer and other collaborators on the test bed project, with respect to the specification of the target grids for the extratropical, tropical and continuous real cases assembled (hopefully agreed at the September 30, 1998 meeting of key investigators with the Program Officer) we will produce a Virtual Test Bed Wind Field (VTB-WF) CD-ROM for all storm cases except Hurricane Danielle, whose wind field may be iterated here at OWI in trial hindcasts to identify gross errors if any, before the final test bed version of the wind field is fixed.
2. Following completion of the analysis of the continuous period January, 1996 to December, 1996

and acceptance of the final hurricane Danielle wind field, the VTB-WF CD-ROM will be completed with the addition of these two cases.

3. We will contribute to the design of the test bed statistical skill assessment package, following which we will be able to prepare a Virtual Test Bed Data Base (VTB-DB) CD-ROM which contains the processed wave data from buoy, platform and altimeter sources.

4. Toward the end of the next contract period, we expect to contribute to the production of the first suite of tests of the test bed against the baseline version of WAM (WAM-4) using a Workstation or PC version of WAM. .

REFERENCES

Cardone, V. J. and D. T. Resio, 1998: An Assessment of Wave Modeling Technology. Fifth International Workshop on Wave Hindcasting and Forecasting. : Calibration of ERS-2 fast Delivery Significant Wave Height and Wind Speed. Report prepared for Oceanweather. Uary 26-30, 1998, Melbourne, FL.

Carter, D. J. T. 1996: Calibration of ERS-2 fast Delivery Significant Wave Height and Wind Speed. Report prepared for Oceanweather.

Cotton, P.D. and D.J.T Carter, 1994: Cross Calibration of Topex, ERS-1, and Geosat Wave Heights. *J. Geo. Res.*, Vol. 99, 25025-25033.

Swail, V. R. and A. T. Cox, 1998: On the use of NCEP/NCAR Reanalysis Surface Marine Wind Fields for a Long Term North Atlantic Wave Hindcast. Submitted to *J. of Atmos. and Ocean. Technol.*

Cardone, V. J. and D. T. Resio, 1998: Wave Climate Modeling. Submitted to *Shore and Beach*. Case Briefs